Short Pulse Applications of HEC-DPSSLs

May 19, 2006

HEC-DPSSL Workshop

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Outline

Philosophy

CPA 101 “a reminder”

Short Pulse conversion tree

Short Pulse applications tree

Nuclear Photo-Science with SP DPSSLs

Philosophy

Chirped Pulse Amplification is pushing 20 years old

Relativistic intensities are now common

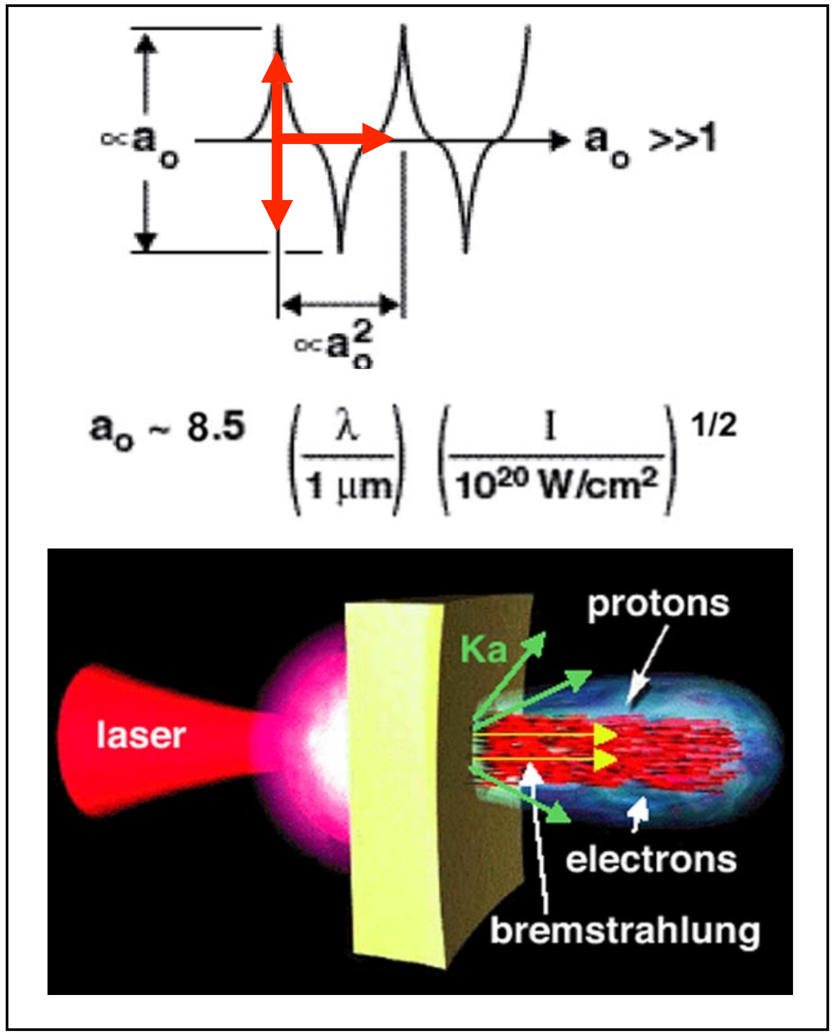
Many "discoveries" have been made & "potential applications" identified

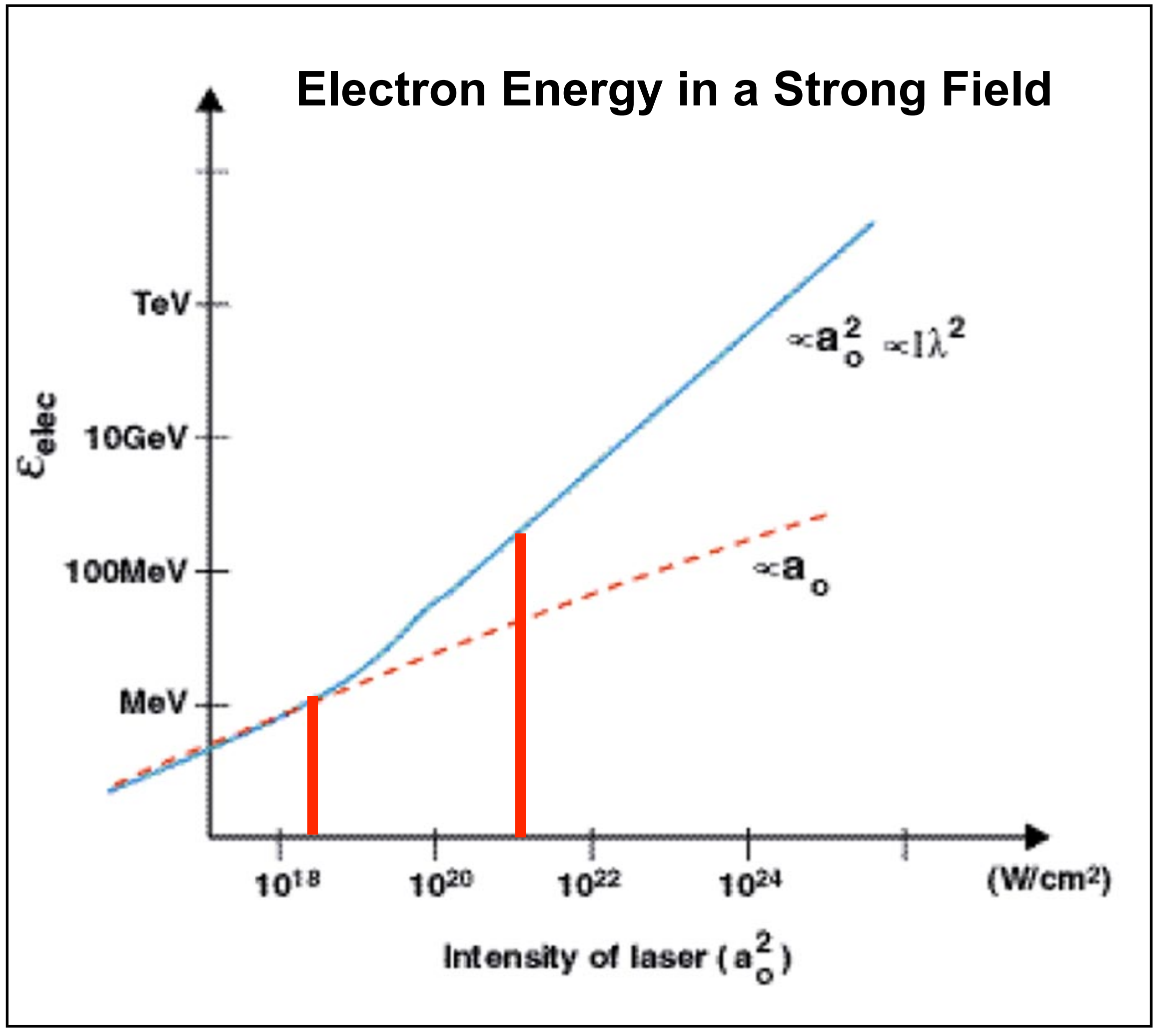
Practicality in many instances is limited by flux

DPSSLs provide the path to higher flux

TW and PW pulses enable ultrahigh intensities and high fluxes of energetic x-rays and particles

PHOTON SCIENCE & APPLICATIONS





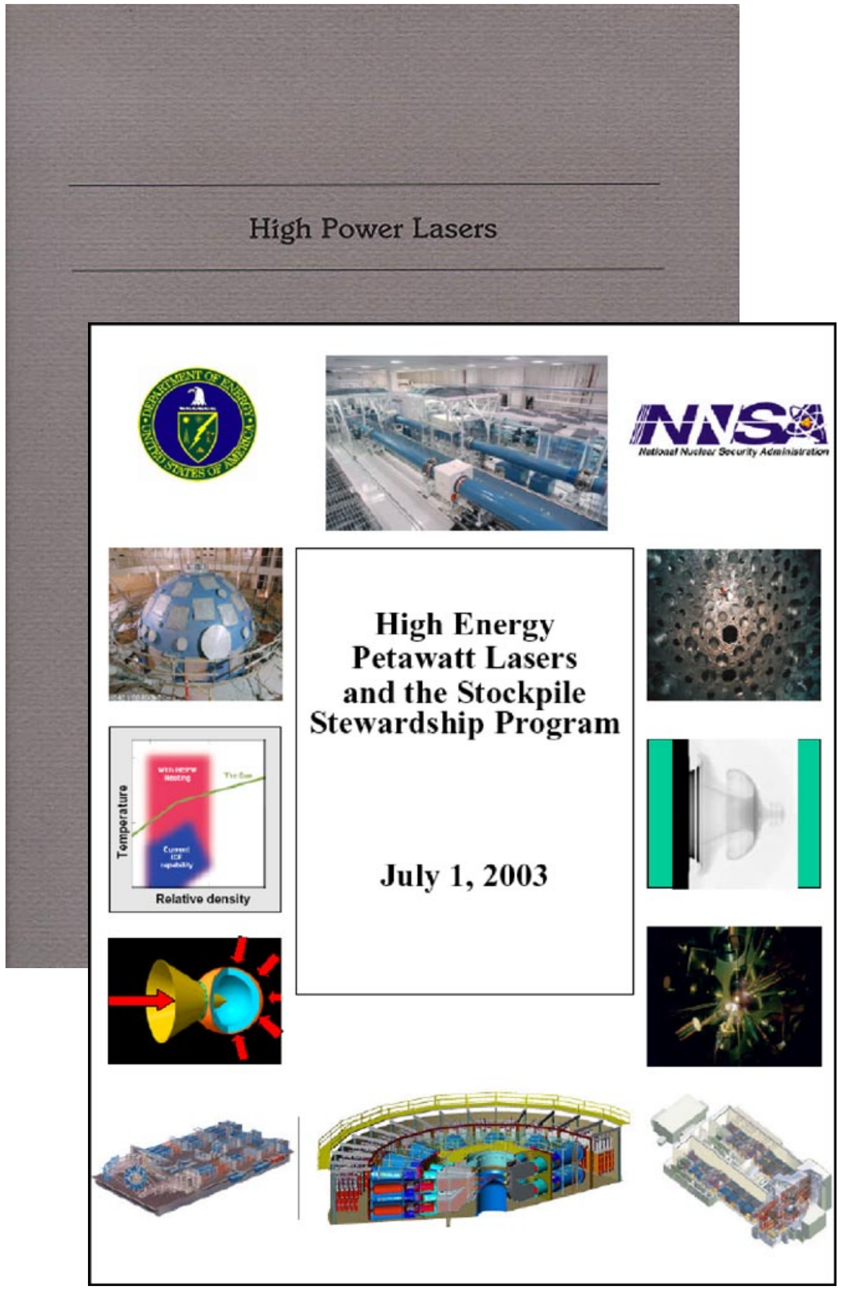
Longitudinal, laser-electron coupling is significant at high intensity, a_0>1

TeV per meter electric fields produce efficient electron acceleration

Energetic electrons can efficiently produce high-energy x rays and protons

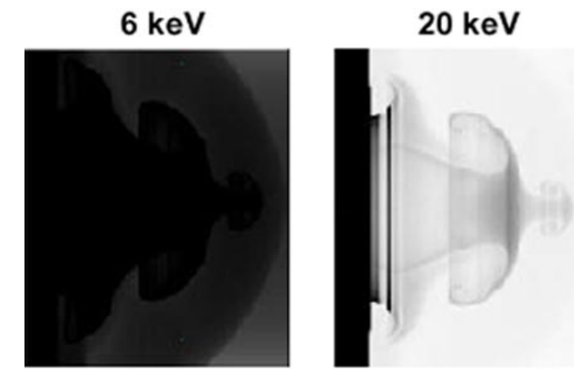
Flux of x-rays and particles is proportional to laser pulse energy

NNSA has outlined the benefits of deploying high energy petawatt capability on the US HEDP facilities



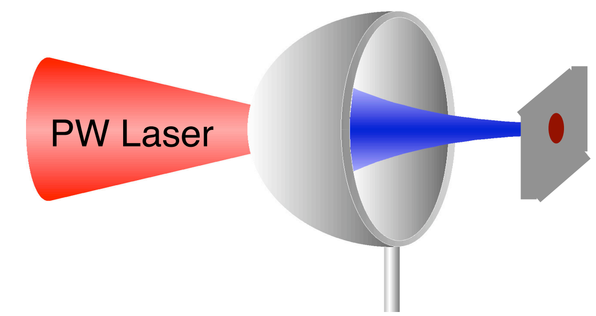
Advanced radiographic capability (ARC)

Multi-kJ, ps pulses enable thick target radiography



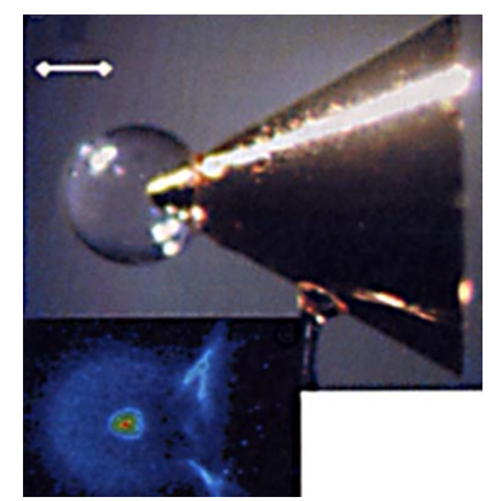
Creation of unique states of matter

Multi-kJ, ps pulses enable proton isochoric heating



Exploration of advanced ignition concepts

10’s of -kJ, ps pulses may allow full-scale demonstration of fast ignition

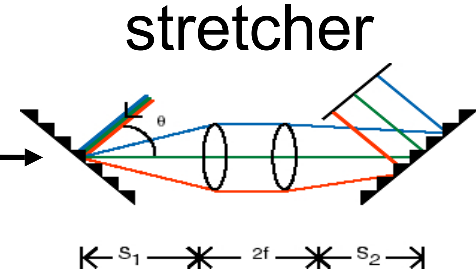


Chirped Pulse Amplification applied to existing long-pulse lasers can produce high energy petawatt pulses

Strictland & Mourou, Opt. Comm.56, 219, 1985

Short Pulse Oscillator

stretcher



Solid State Laser Amplification Chain

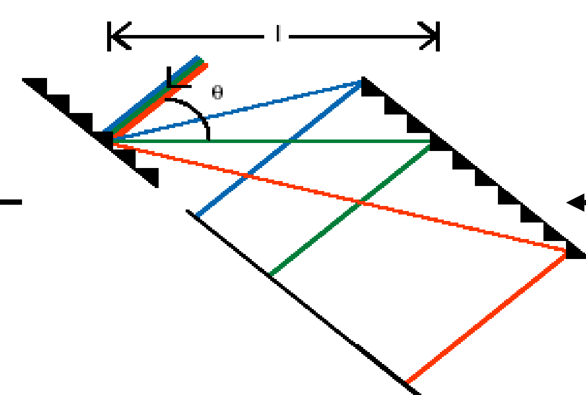
- Peak Power Increase is Proportional to $\Delta t_{stretch} > 1000$

CPA Circumvents Short Pulse Damage in the Amplifier
Stretched pulse duration is not arbitrary
Grating size is linked to stretched pulse duration
Grating separation is linked to bandwidth and stretched pulse duration

- Stored Energy is extracted safely

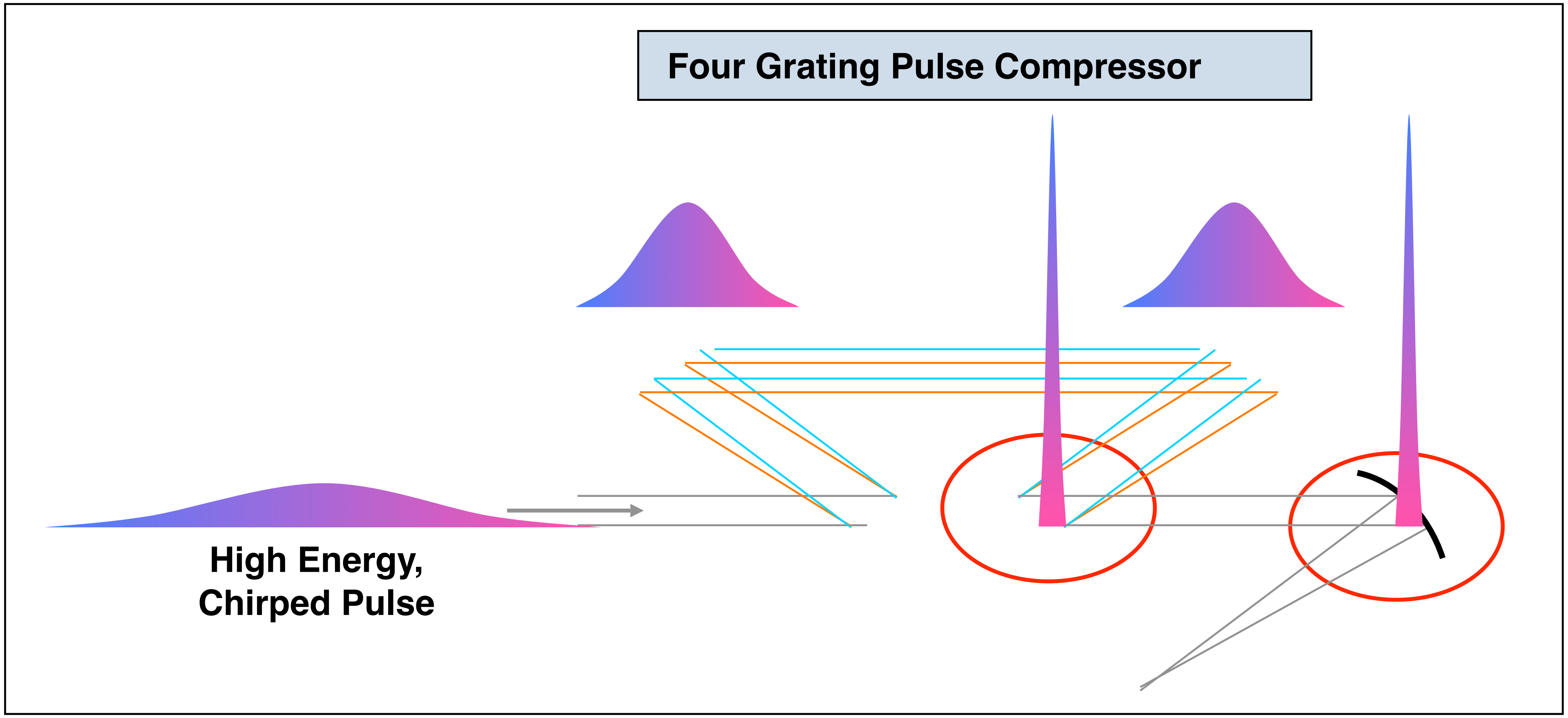
$I \sim J_{sat}/\Delta t_{stretch}$

$I < I_{damage}$



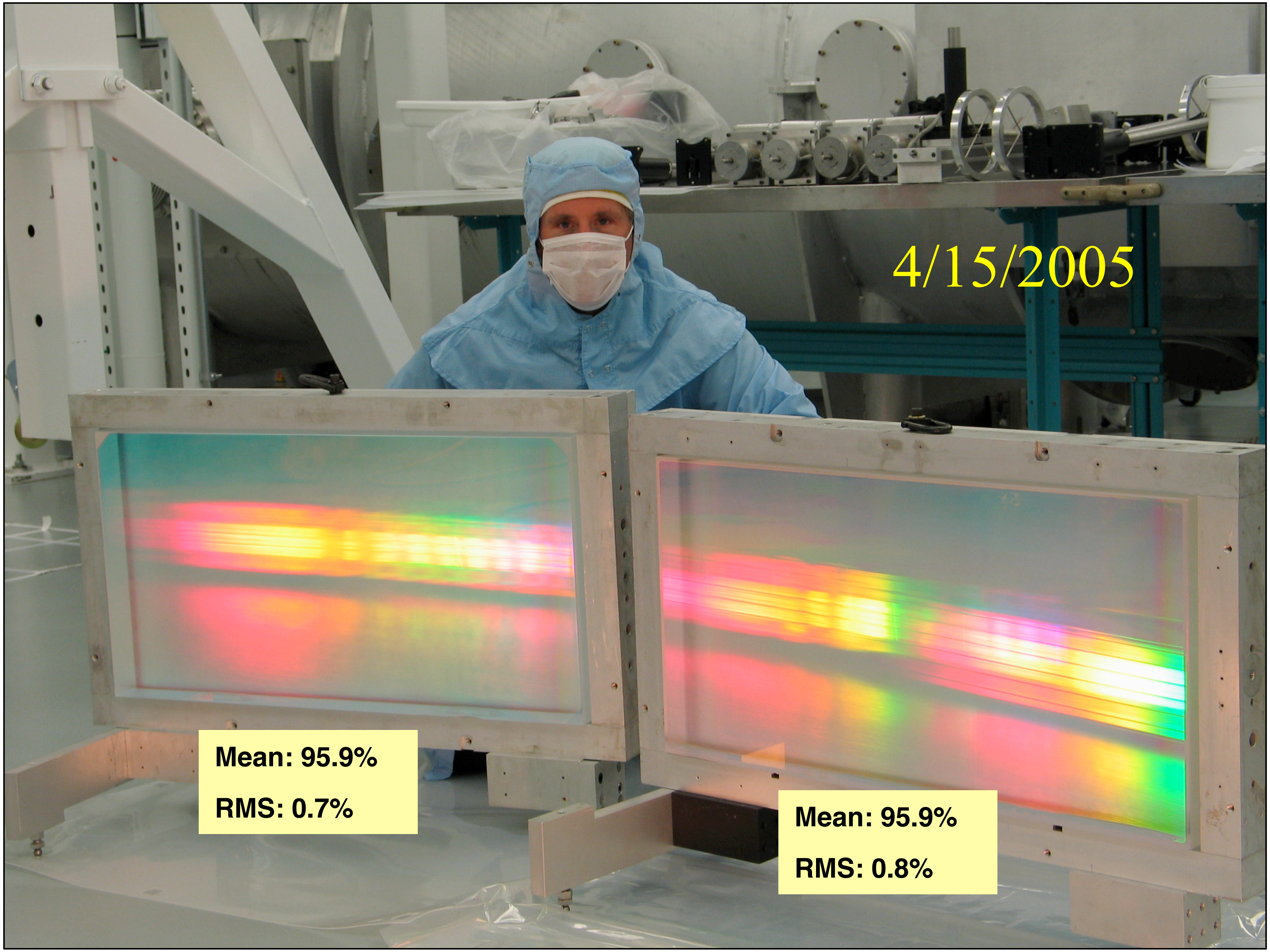
compressor

The fundamental HEPW issue is final optic damage
CPA does NOT eliminate final optic damage

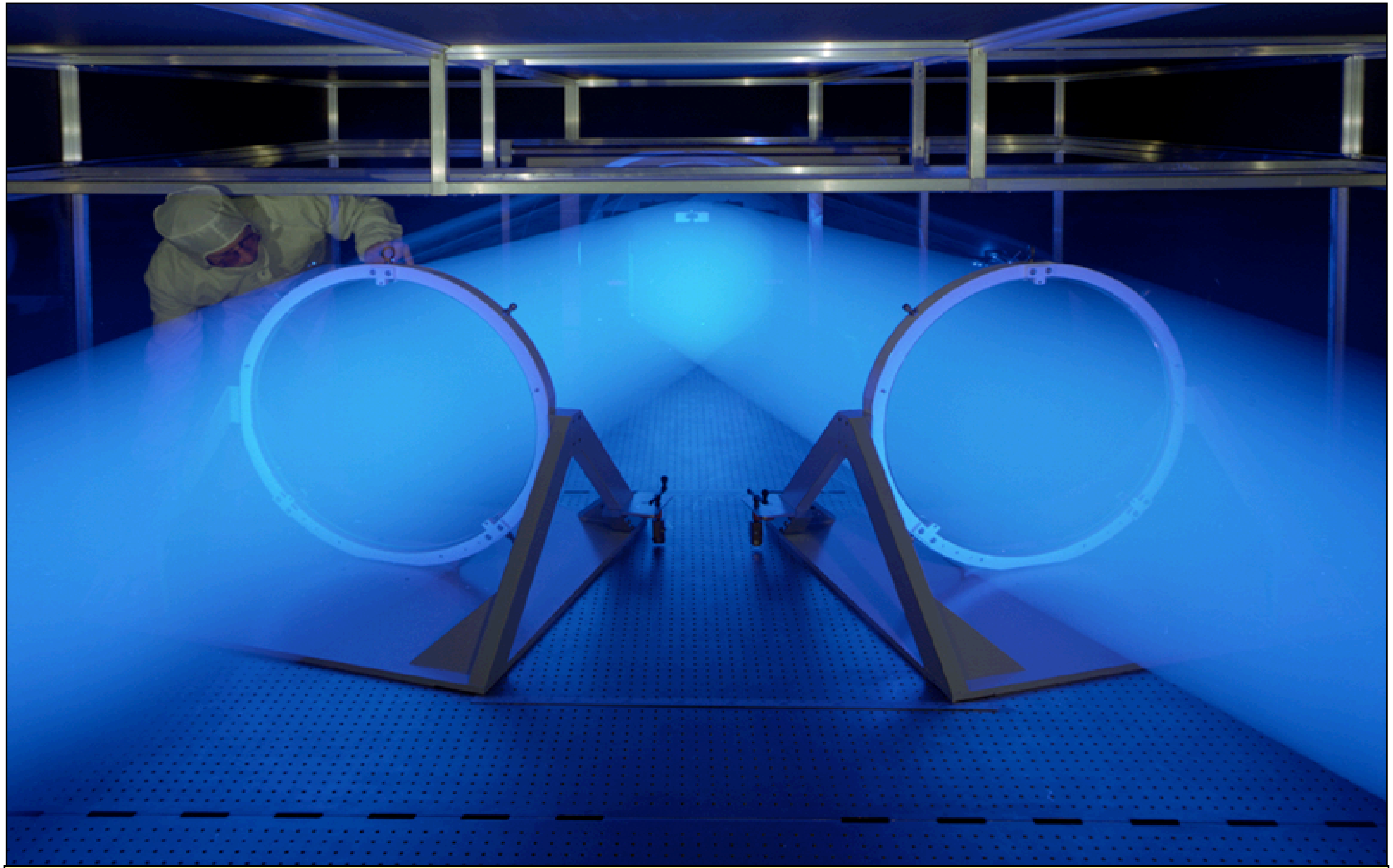


- Pulse is SHORT and energy is HIGH on the Final Grating and Focusing Optic
  Intensity dependent damage of “Final Optics” is THE BIG problem

First 40cm x 80cm MLD production gratings were delivered to Titan (300J,500fs) Laser Project at LLNL

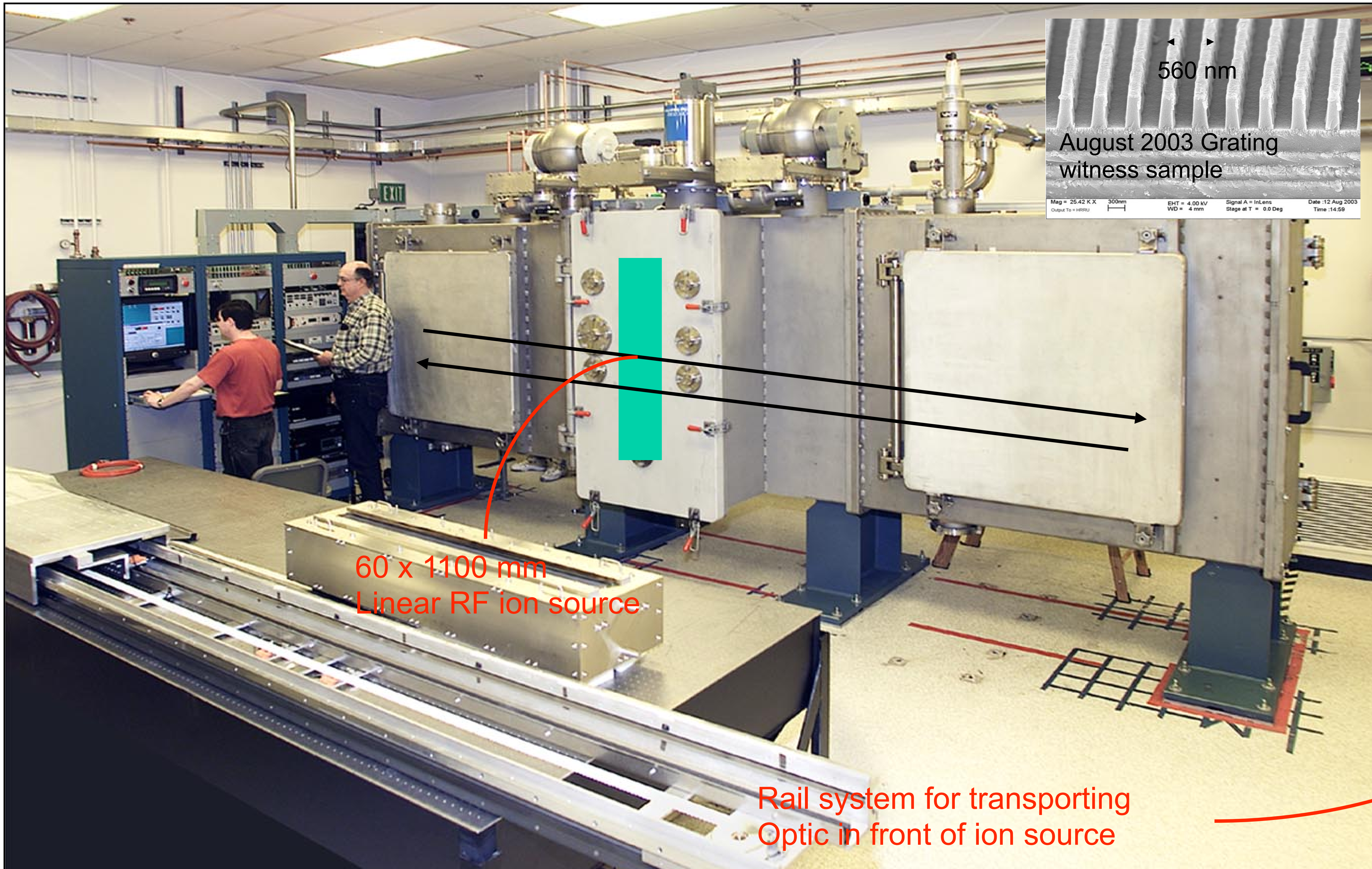


World’s largest holographic exposure station for grating fabrication has been developed at LLNL



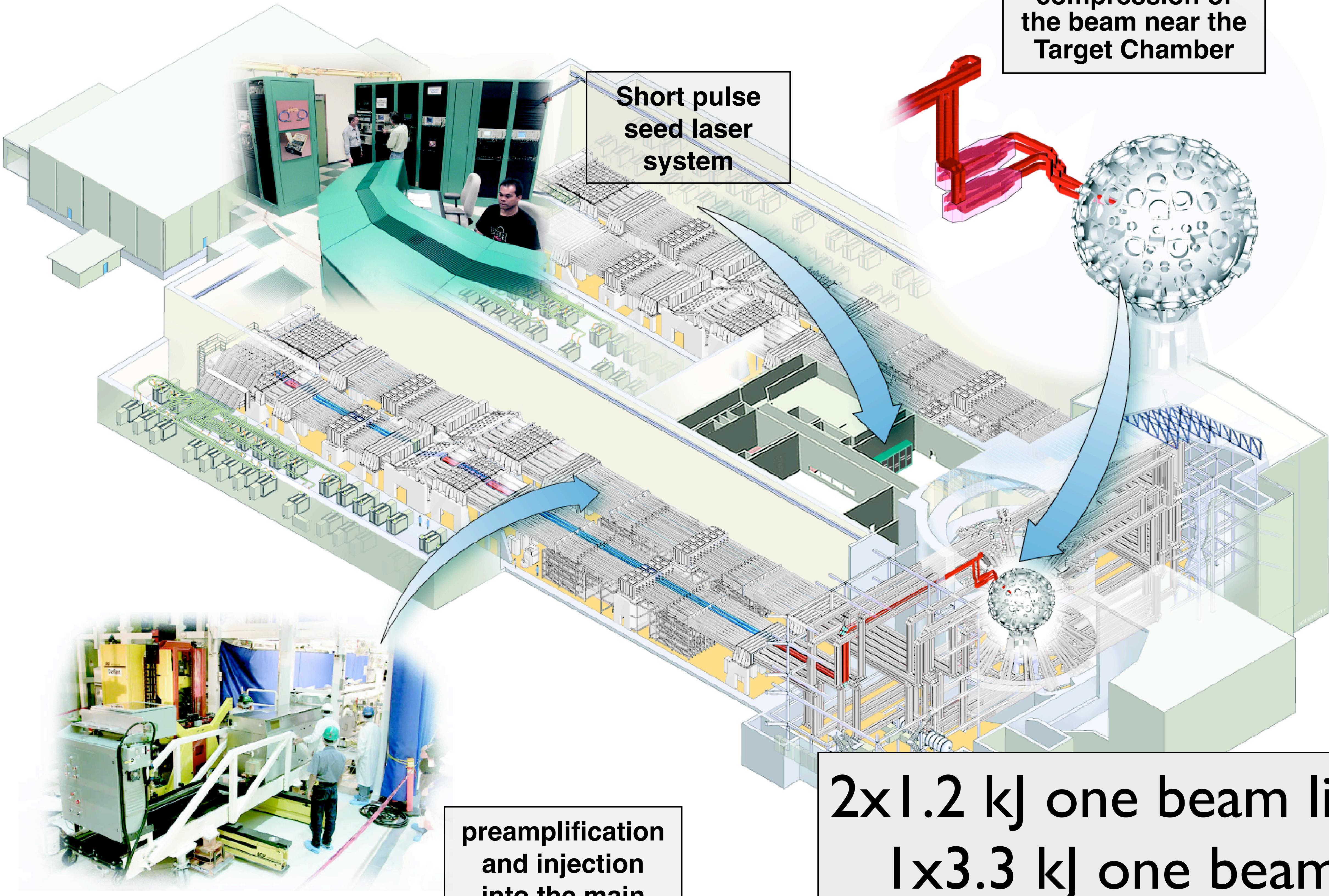
Used to create grating structures in photo-resist for metal coating or transfer etching. Operational since 1997 w/ 1100 mm diameter optics

World's largest ion beam milling machine commissioned in April of 2003 at LLNL



Capable of submicron pattern generation uniformly over 2 x 1 meter apertures. Represents a 500% increase over existing MLD etch tools.

High Energy Petawatt Pulses on NIF

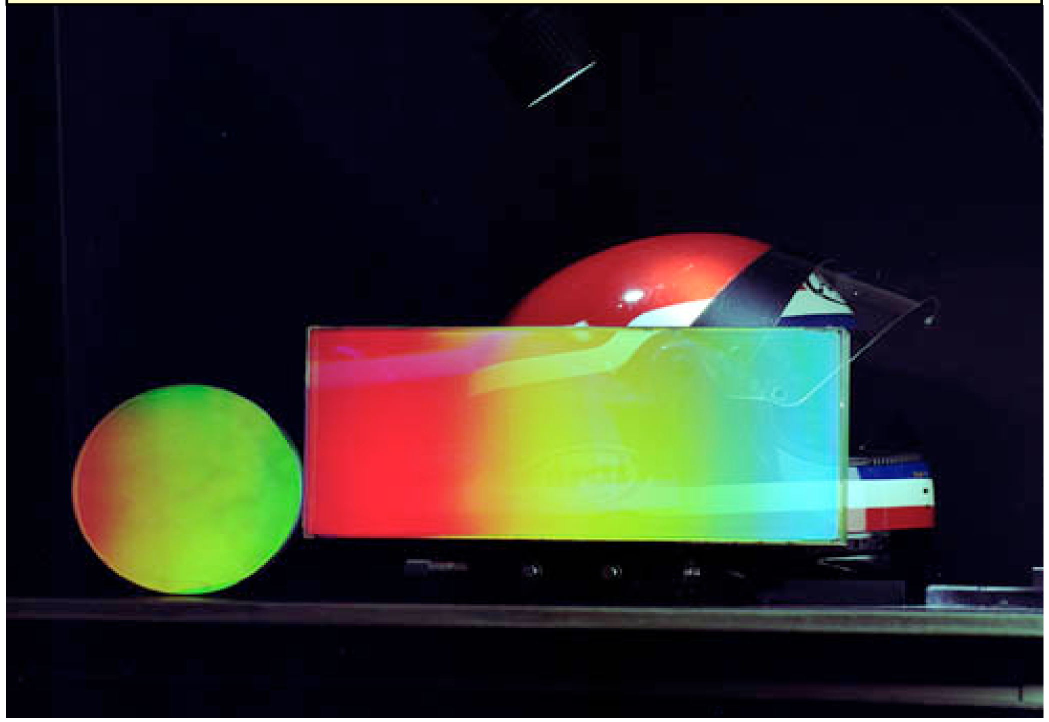


2x1.2 kJ one beam line
1x3.3 kJ one beam
13.2 kJ one quad

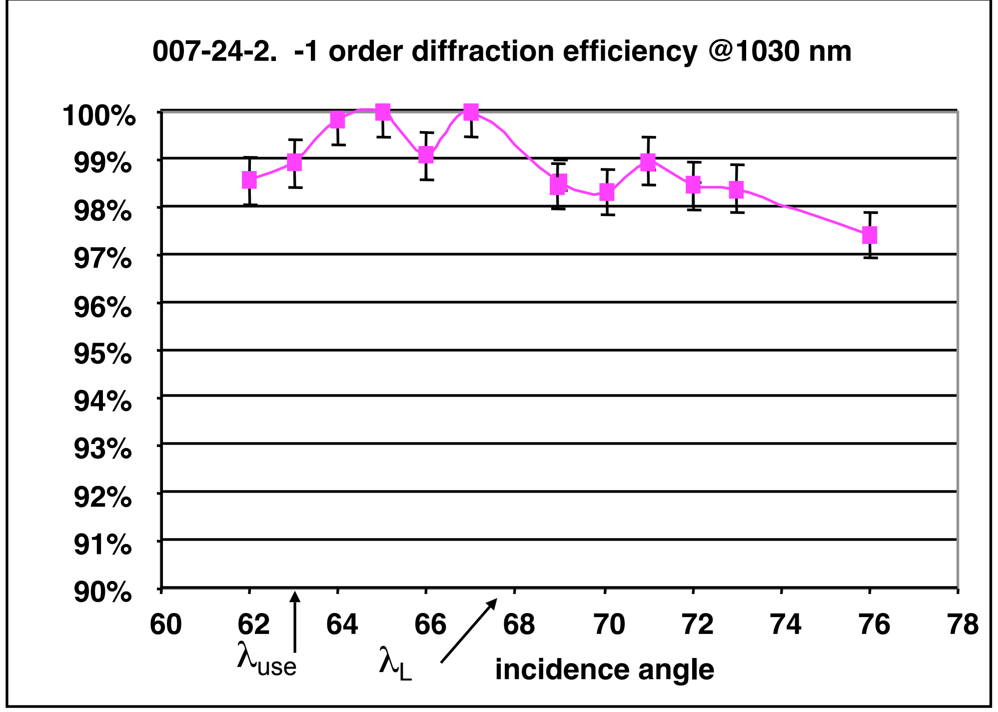
High efficiency MLD gratings were produced for a high average power laser machining application in 2000

- **MLD gratings are patented by LLNL**
  - **— Commercial licenses have been executed**
- **Largest aperture MLD grating available commercially is ~40 cm x 20 cm**

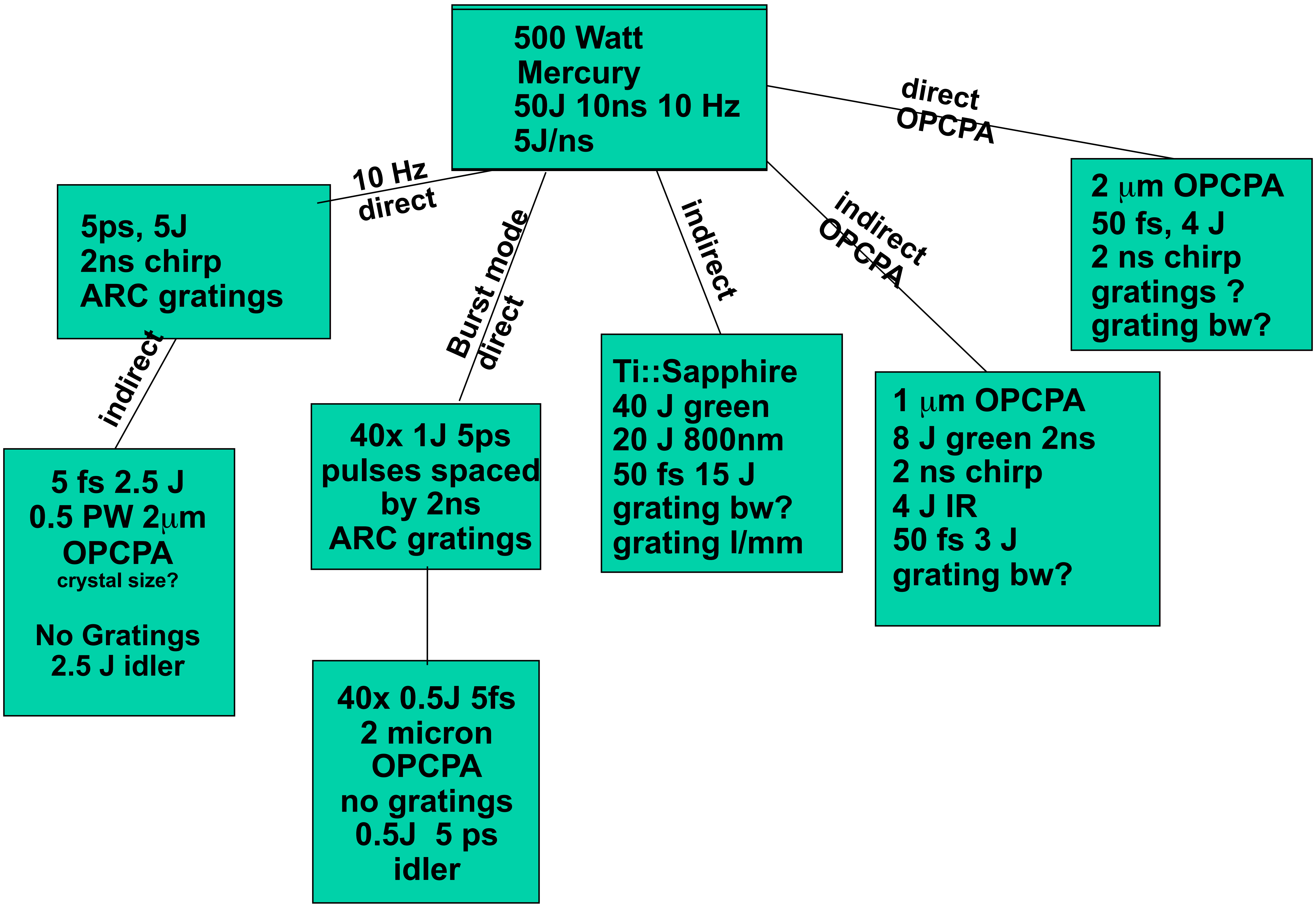
355 x 150 mm MLD Grating for 50 watt, 2 KHz, 2 Picosecond Machining Laser (2000)



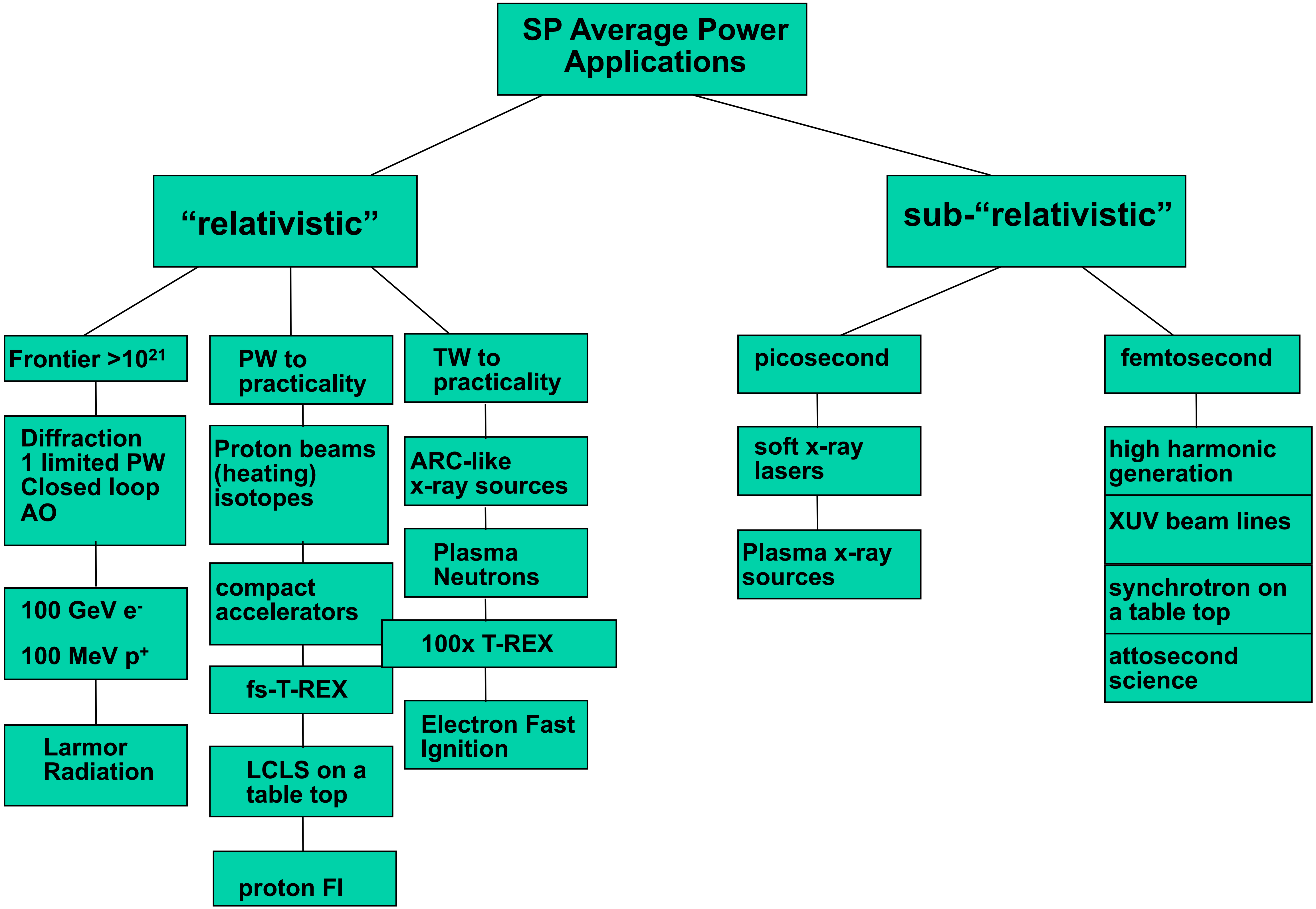
> 99%, World Record for Diffraction Efficiency



Short Pulse Conversion Tree

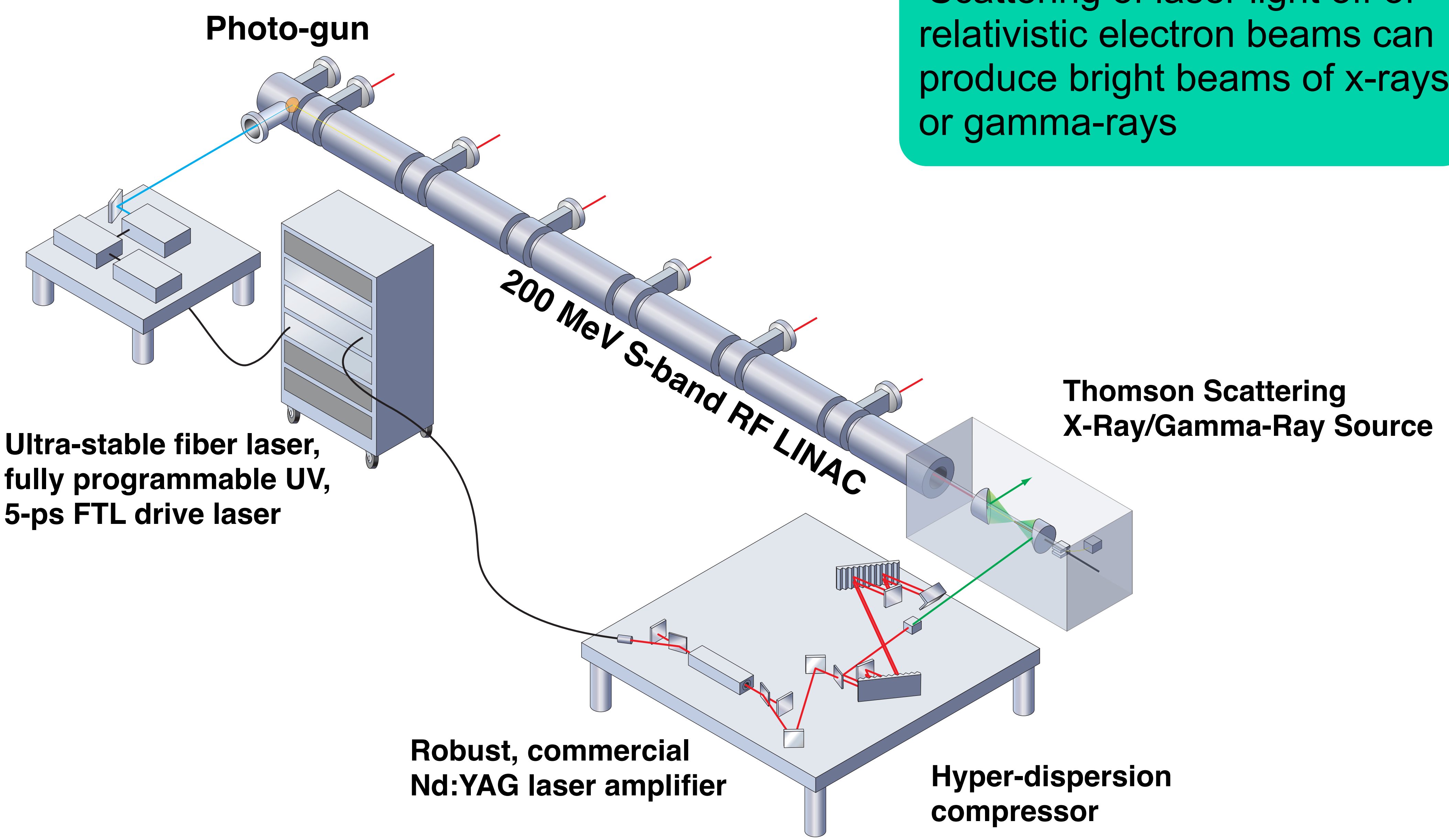


Short Pulse - Applications Tree

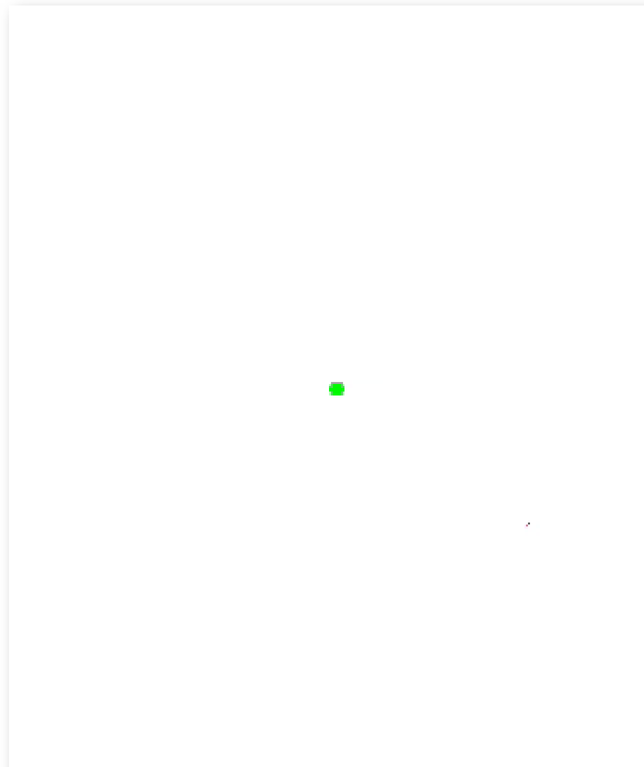


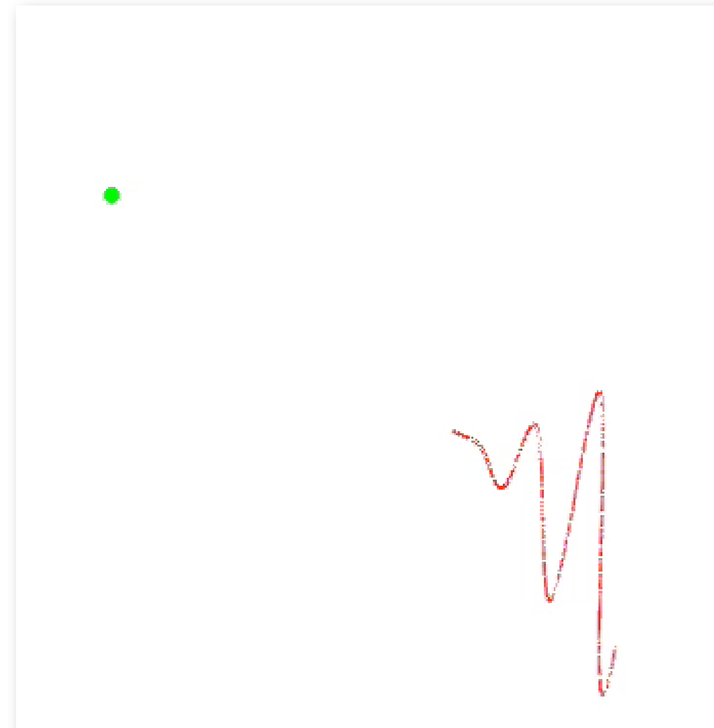
T-REX: *Thomson Radiated Extreme X-Rays*

Scattering of laser light off of relativistic electron beams can produce bright beams of x-rays or gamma-rays



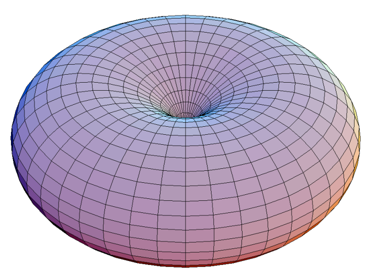
What is Relativistic Thomson Scattering?

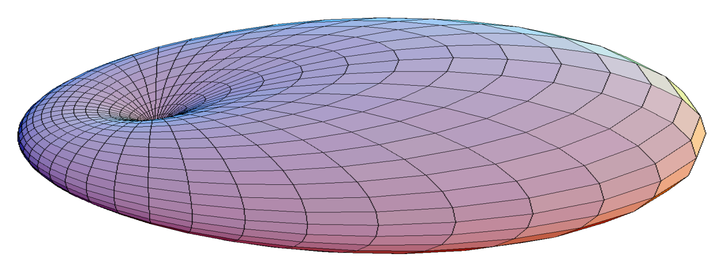




Electron Frame

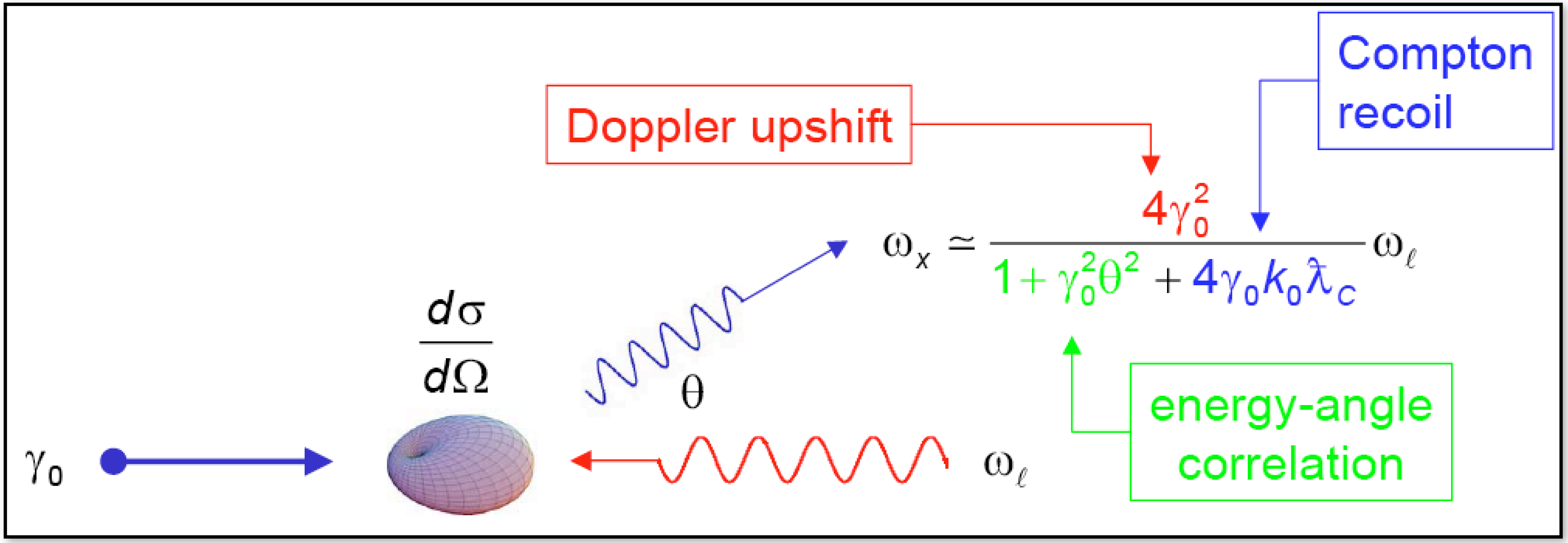
Lab Frame





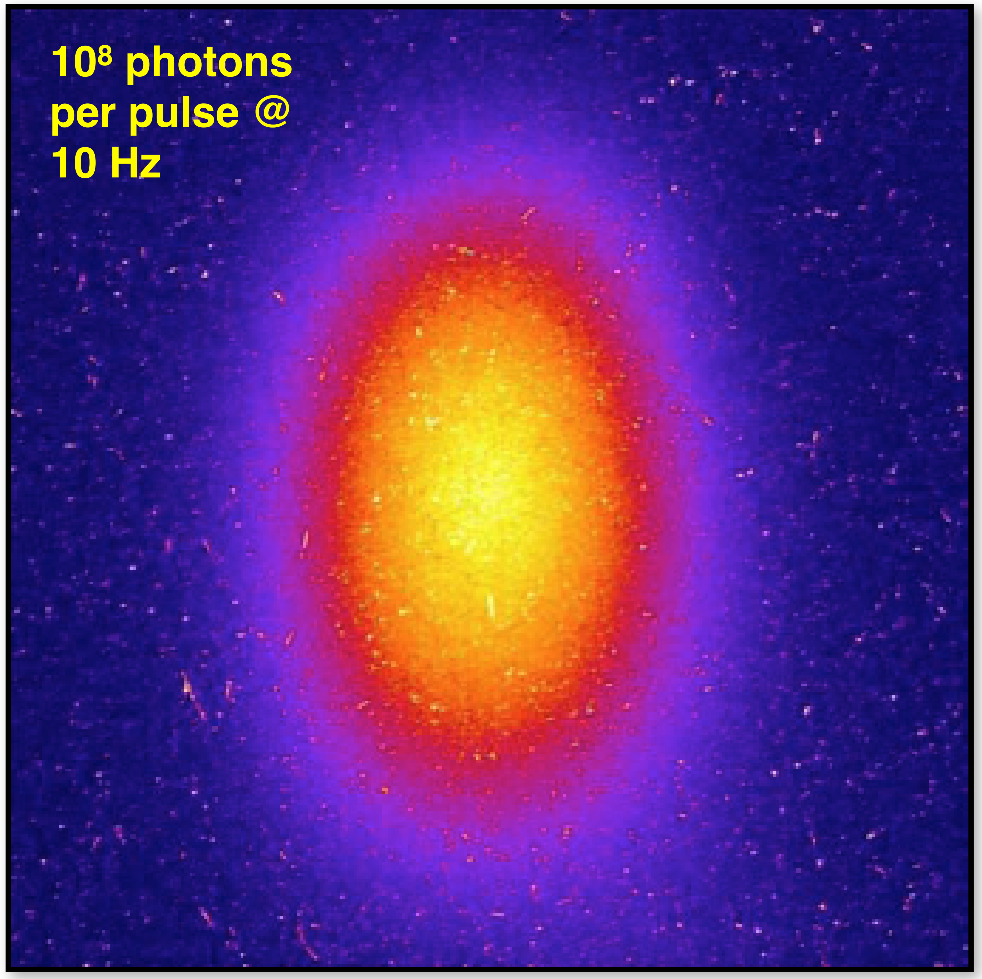
The electron re-radiates incident laser light at shorter wavelength (relativistic Doppler upshift) in narrow cone

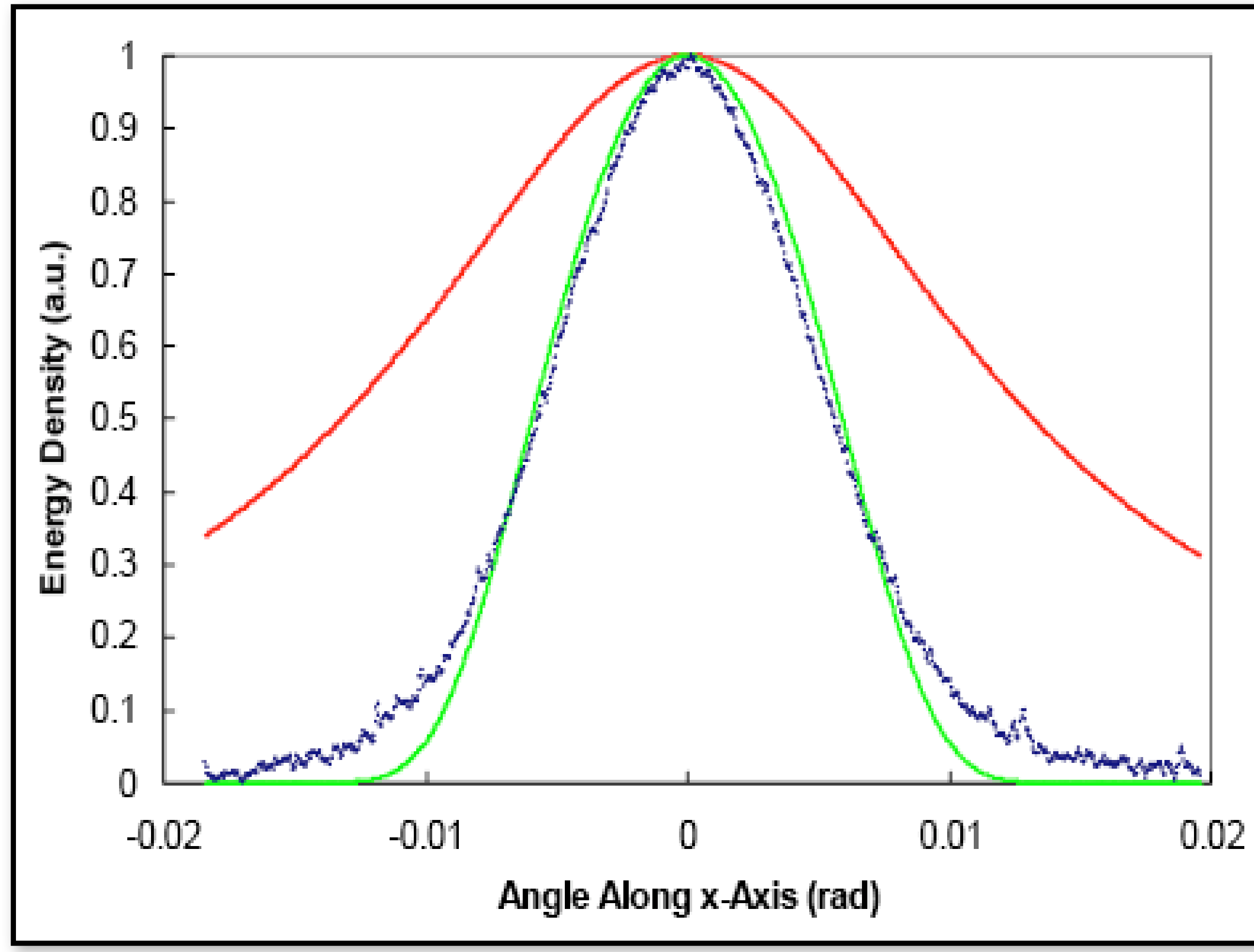
What is Relativistic Thomson Scattering?



Energy-momentum conservation yields Doppler upshift
Thomson scattering cross-section is very small (6 X 10^{-25} cm^2)

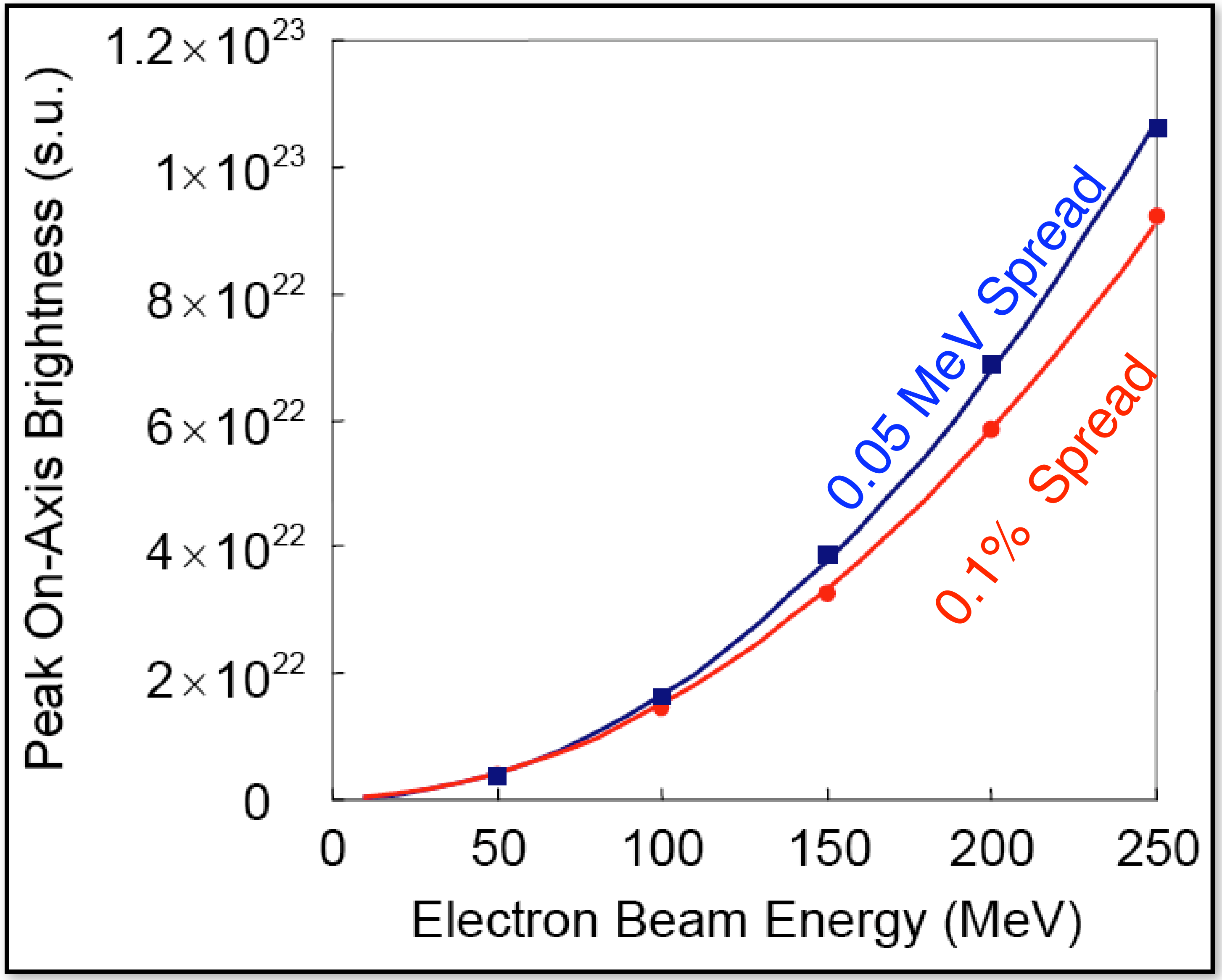
70 keV x-rays generated at LLNL via Thomson-scattering





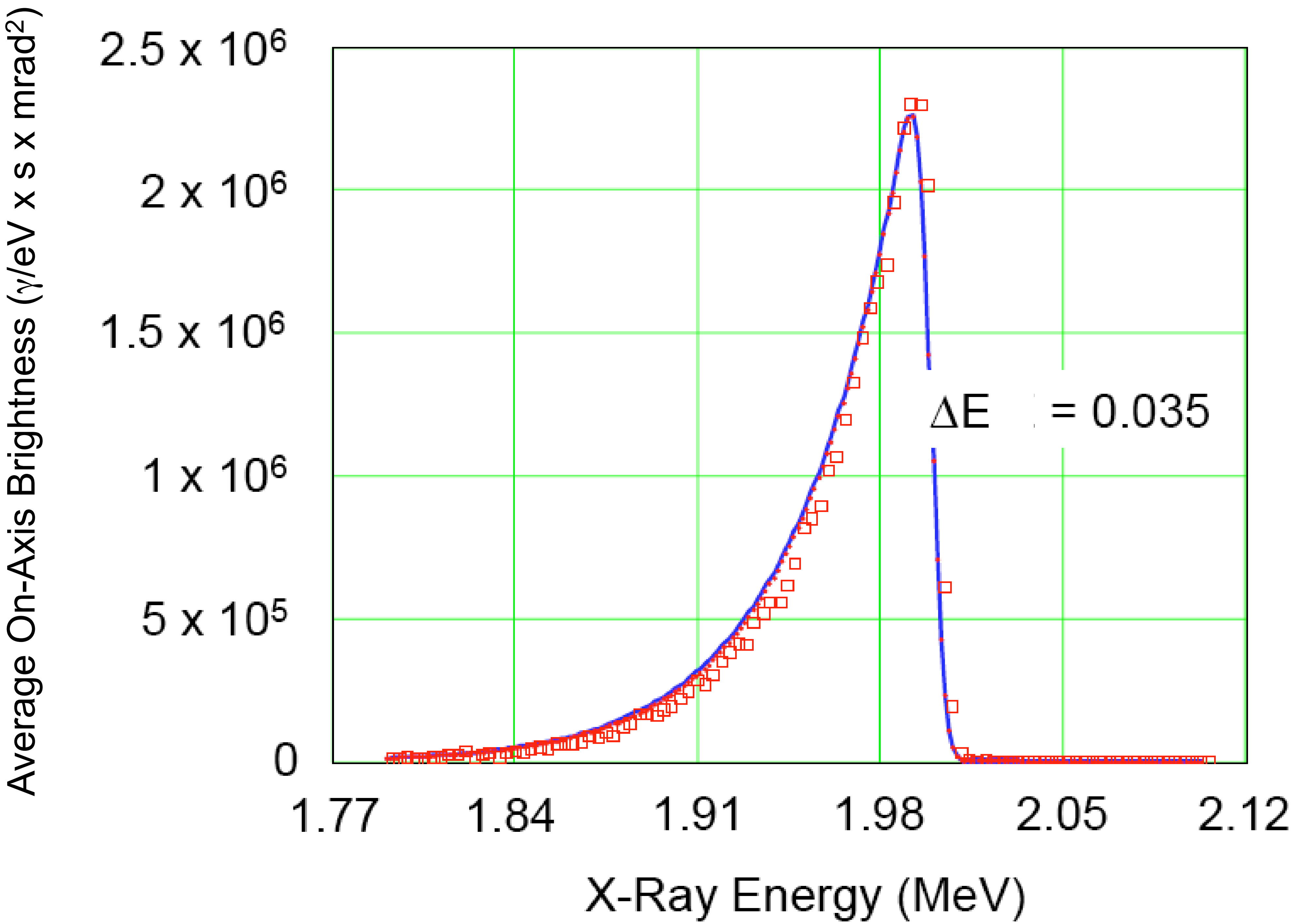
2 sophisticated 3D codes, & analytical theory developed & benchmarked

Thomson-Radiated Extreme X-ray (T-REX) brightness scales very rapidly with electron beam energy

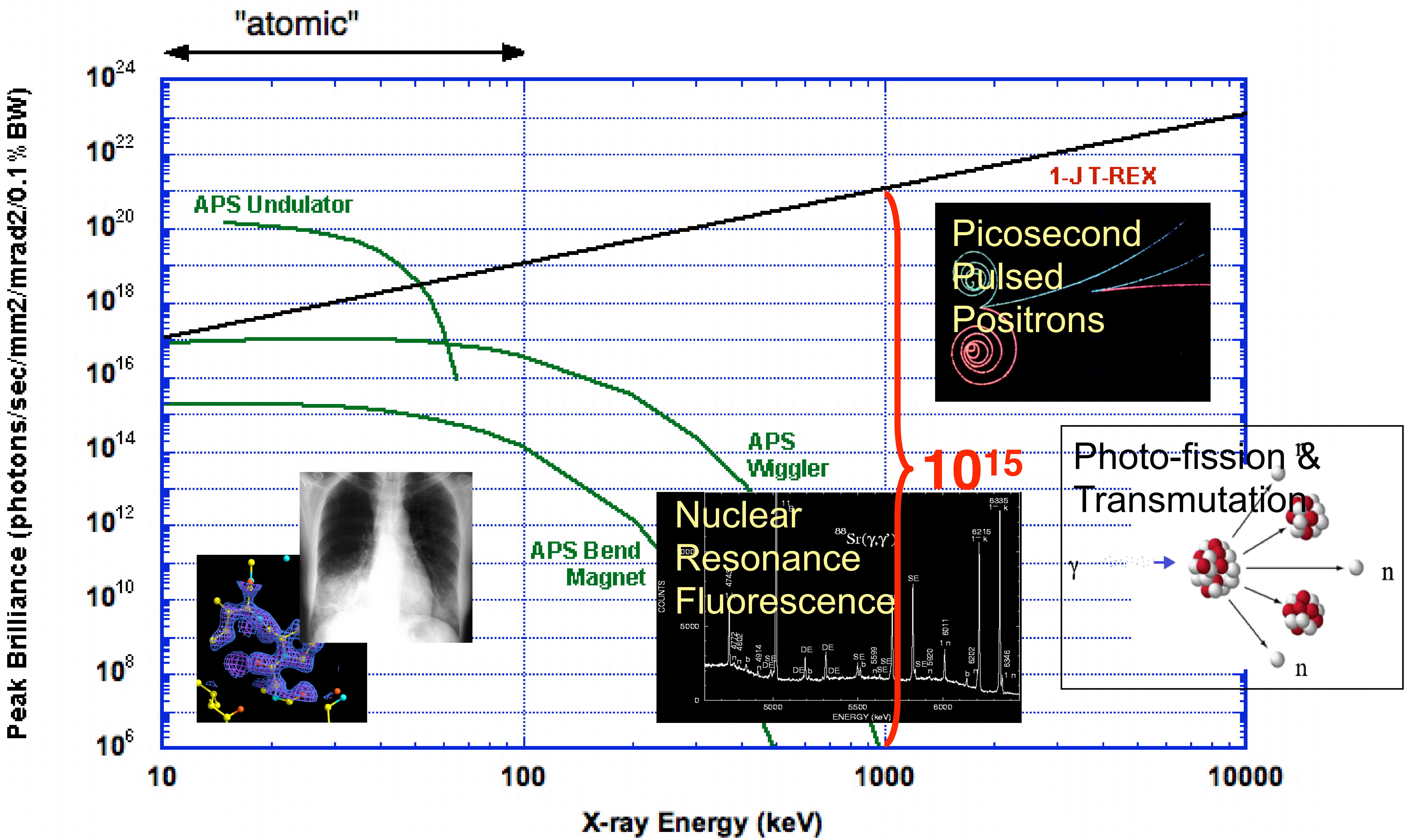


γ-ray brightness is mainly determined by e-beam phase space;
$\gamma^2/\ \varepsilon^2$ is the key parameter

Example of a narrow-band, high-brightness, 2-MeV Thomson-Radiated Extreme X-ray (T-REX) spectrum

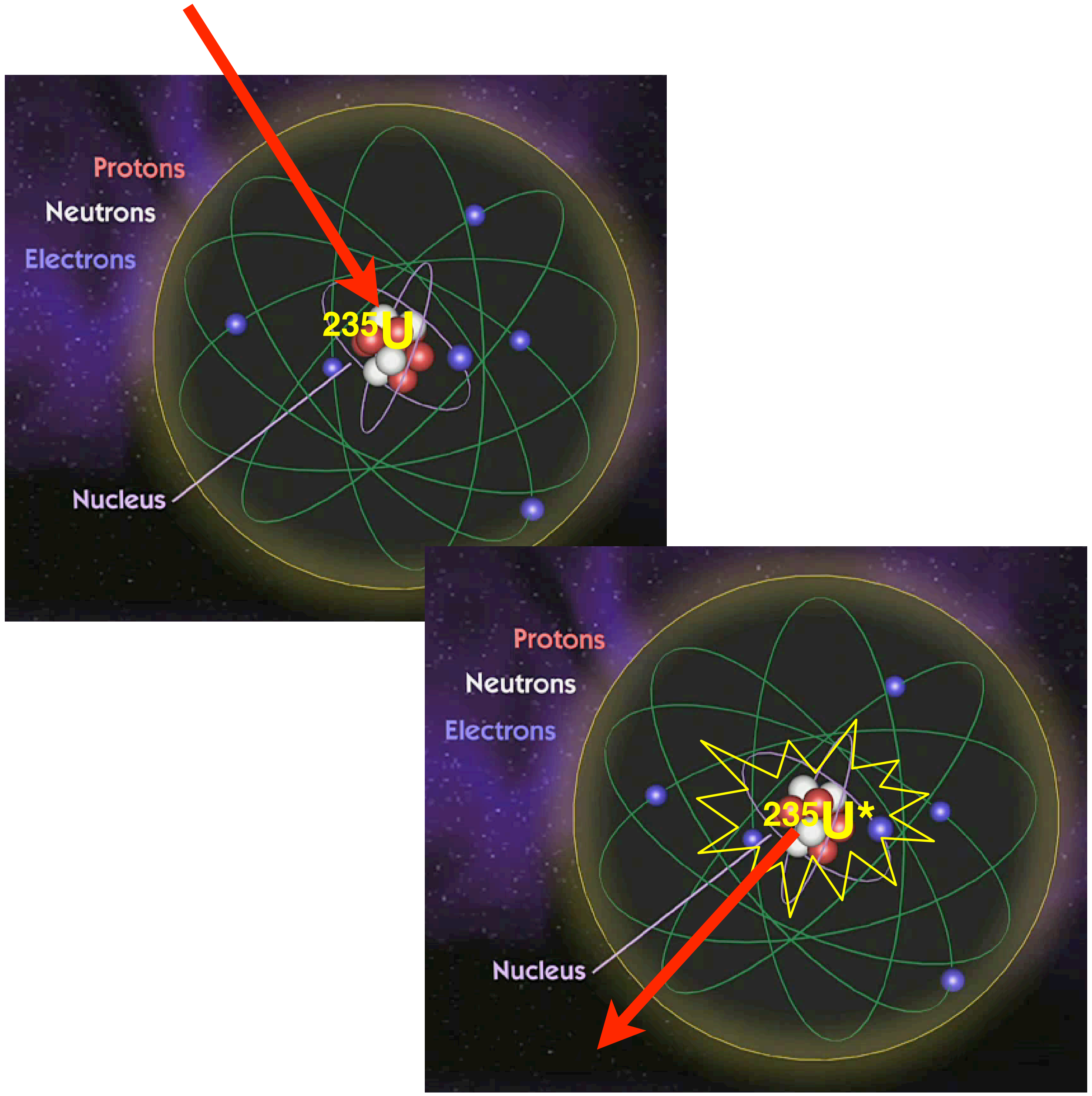


The dawn of Nuclear Photo-Science? T-REX brightness will enable an entirely new field of study and new



Peak Brilliance for T-REX at >1 MeV will exceed the world's best synchrotrons by >15 orders of magnitude
T-REX may do for nuclear spectroscopy & physics what the laser did for atomic spectroscopy & physics

Nuclear resonance fluorescence (NRF)



Incident photon absorbed by nucleus

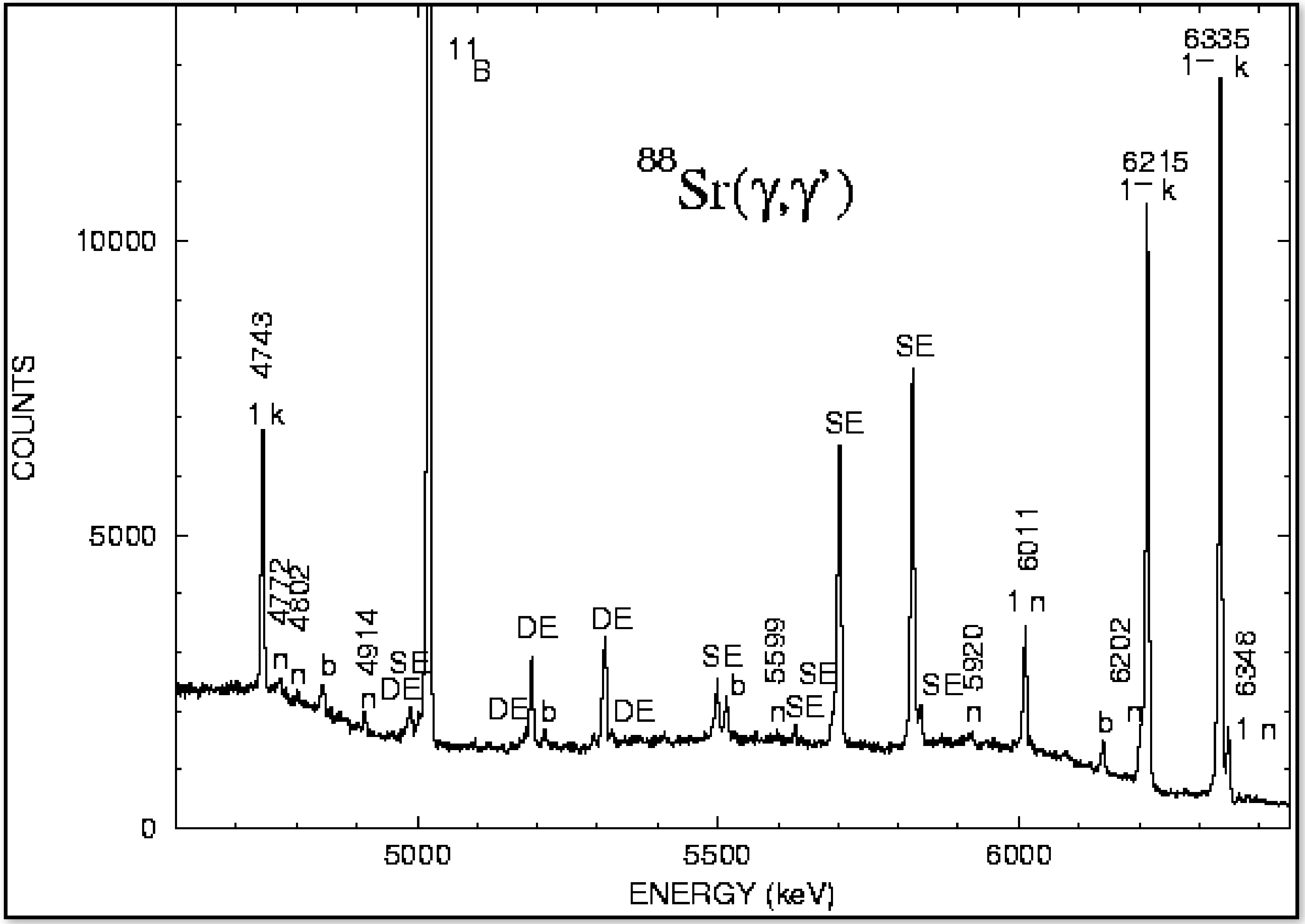
At certain resonance energies

Excited state quickly re-emits photons at the same or different frequencies

Energy scale is MeV!

In complete analogy with atomic fluorescence

Nuclear resonance fluorescence (NRF) provides a unique fingerprint for each ISOTOPE



Cross sections can be large enough to detect grams of material

Got SNM?

7,000,000 containers per year
20 kg of ^{235}U = very bad day

The potential impact and scenarios for "Nuclear Terrorism" have been the subject of many recent reports

PHOTON SCIENCE & APPLICATIONS

DOCUMENTED BRIEFING

Aum Shinrikyo, Al Qaeda, and the Kinshasa Reactor

Implications of Three Case Studies for Combating Nuclear Terrorism

Sara Daly, John Parachini, William Rosenau

Prepared for the United States Air Force

RAND PRO

United States Government Accountability Office

GAO

Testimony

Before the Subcommittees on the Prevention of Nuclear and Biological Attack and on Emergency Preparedness, Science, and Technology, Committee on Homeland Security, House of Representatives

For Release on Delivery Expected at 2:00 p.m. EDT Tuesday, June 21, 2005

COMBATING NUCLEAR SMUGGLING

Efforts to Deploy Radiation Detection Equipment in the United States and in Other Countries

Statement of Gene Aloise, Director Natural Resources and Environment

840T

Order Code RL32595

CRS Report for Congress

Received through the CRS Web

Nuclear Terrorism: A Brief Review of Threats and Responses

September 22, 2004

Jonathan Medalia
Specialist in National Defense
Foreign Affairs, Defense, and Trade Division

Report of the Defense Science Board Task Force
on
Preventing and Defending Against Clandestine Nuclear Attack

DEPARTMENT OF DEFENSE UNITED

Office of the U
For Acquisitio
Washing

Abt

Abt Associates Inc.

The Economic Impact of Nuclear Terrorist Attacks on Freight Transport Systems in an Age of Seaport Vulnerability

Contract # DTRS57-03-P-80130

Executive Summary

Cambridge, MA
Lexington, MA
Hadley, MA
Bethesda, MD

Occasional Paper No. 8

After 9/11: Preventing Mass-Destruction Terrorism and Weapons Proliferation

arletta, ed.

onproliferation Strategy Group

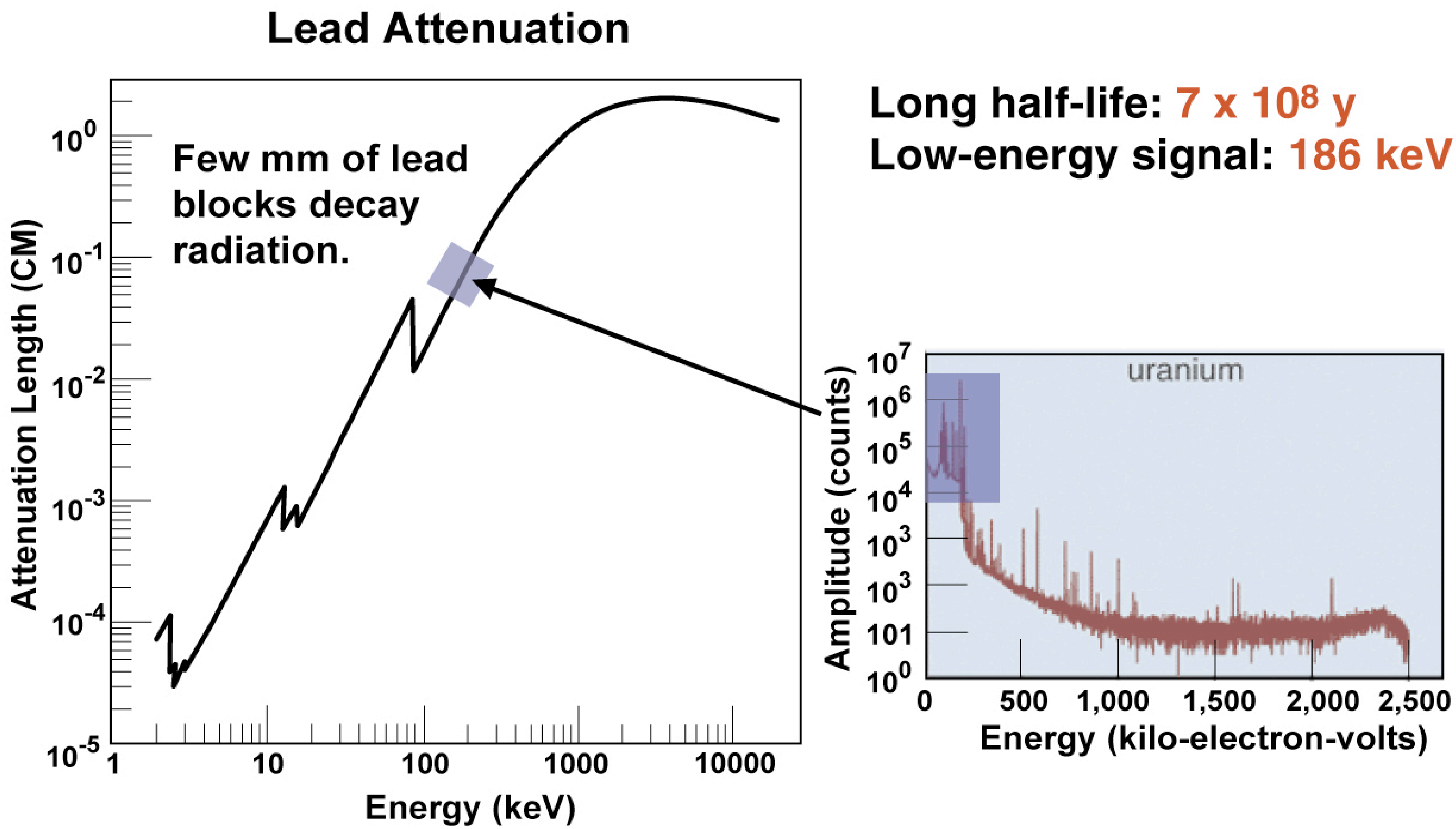
FOR NONPROLIFERATION STUDIES

Table 1-1

Deaths and Damages of a Nuclear Terrorist Attack on a Major Seaport or Washington DC

Deaths	50,000 (Port Elizabeth) – 1,000,000 (Manhattan)
Value Statistical Lives Lost @ $3 million each	$150 Billion - $ 3 Trillion (30% of US GDP)
Property Damage – Direct	$50 – 500 Billion
Trade Disruption	$100 – 200 Billion
Indirect Costs (Direct times multiplier of 2)	$300 – 1,400 Billion (1.4 Trillion)
Total First Year Costs	Hundreds of Billions to Trillions (not including cost of lives lost)

Finding shielded highly enriched uranium (HEU) is a Grand Challenge

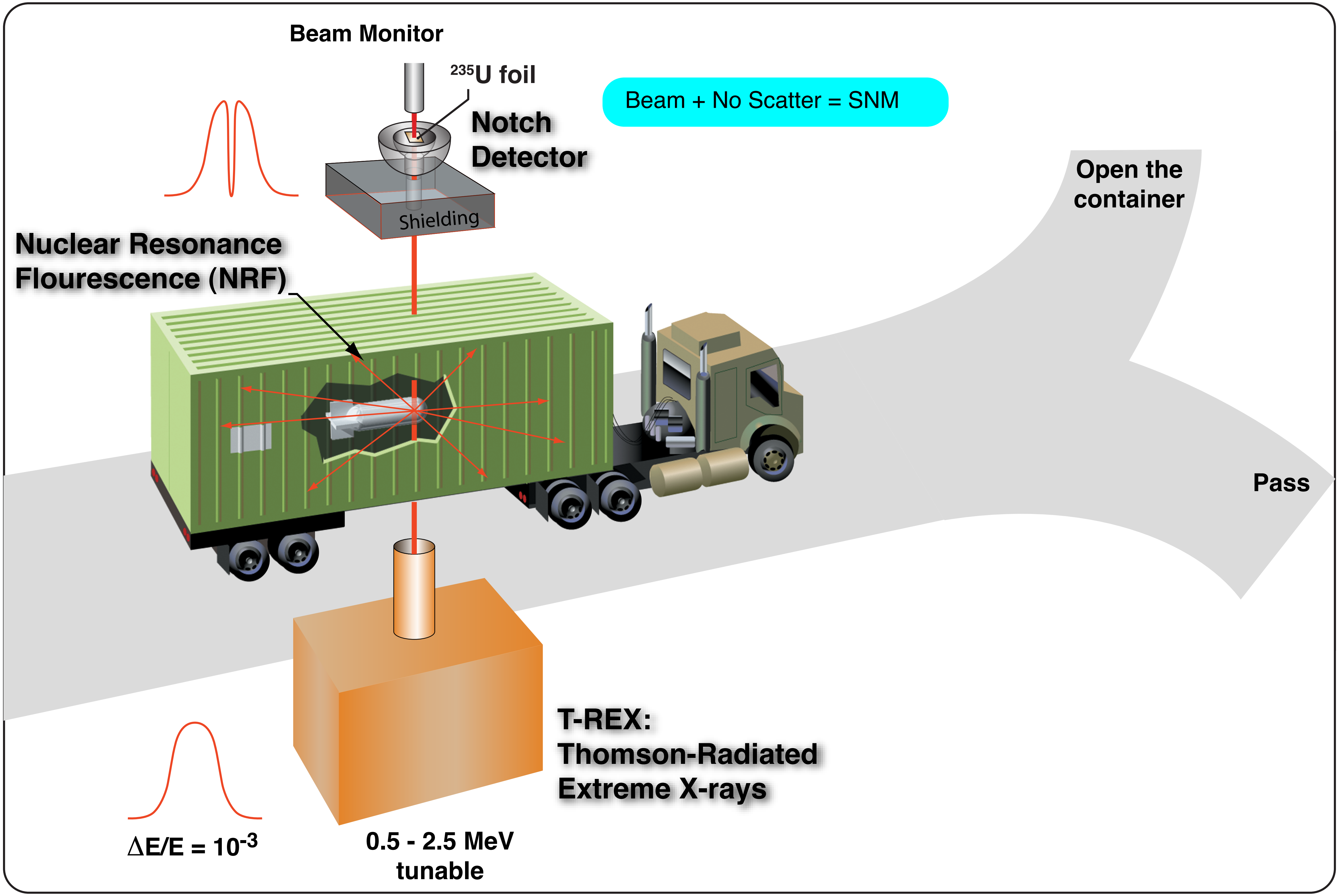


Long half-life: 7 x 10^8 y
Low-energy signal: 186 keV

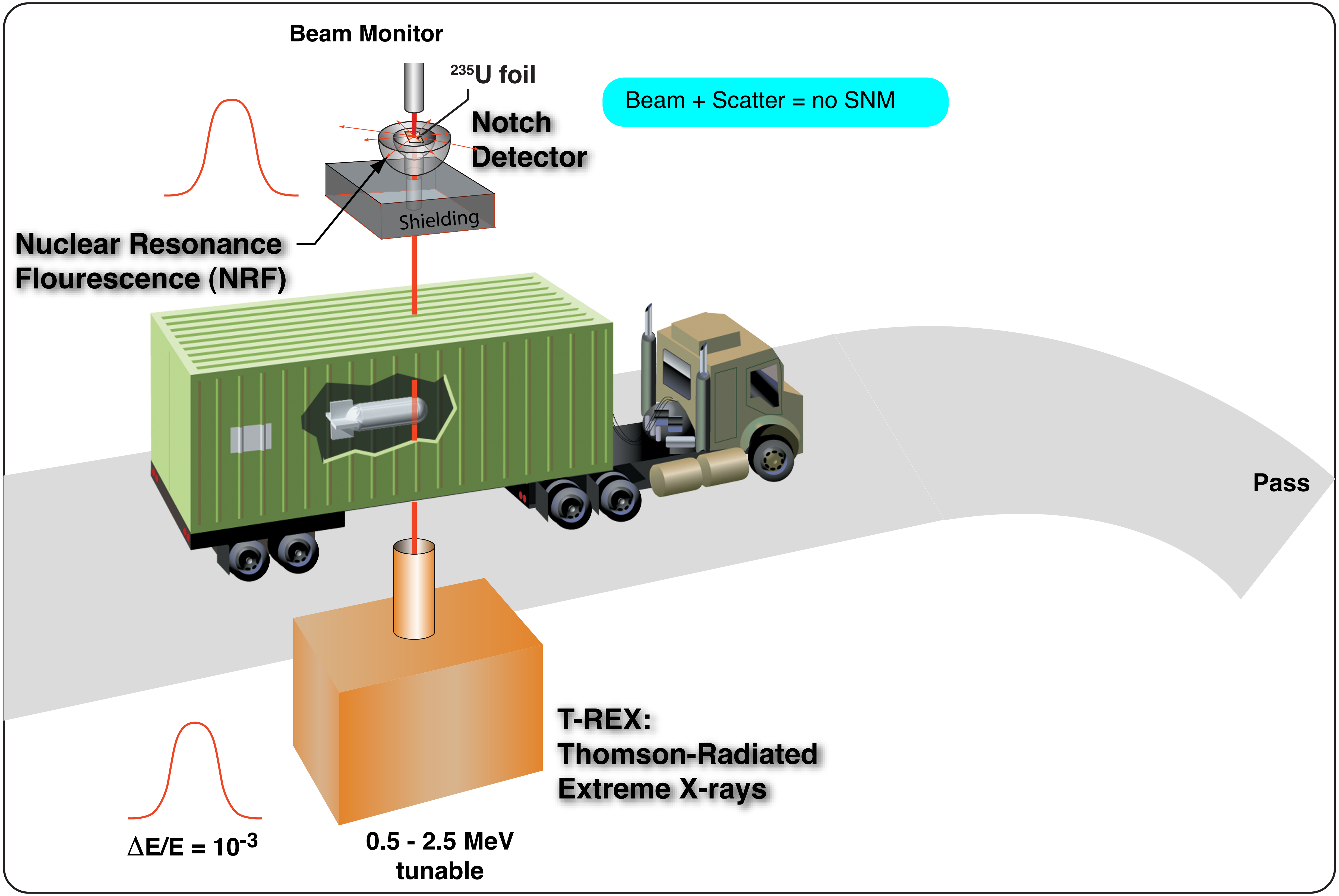
Passive detection won't work

NIF-0905-11353 L1
13CB/tr

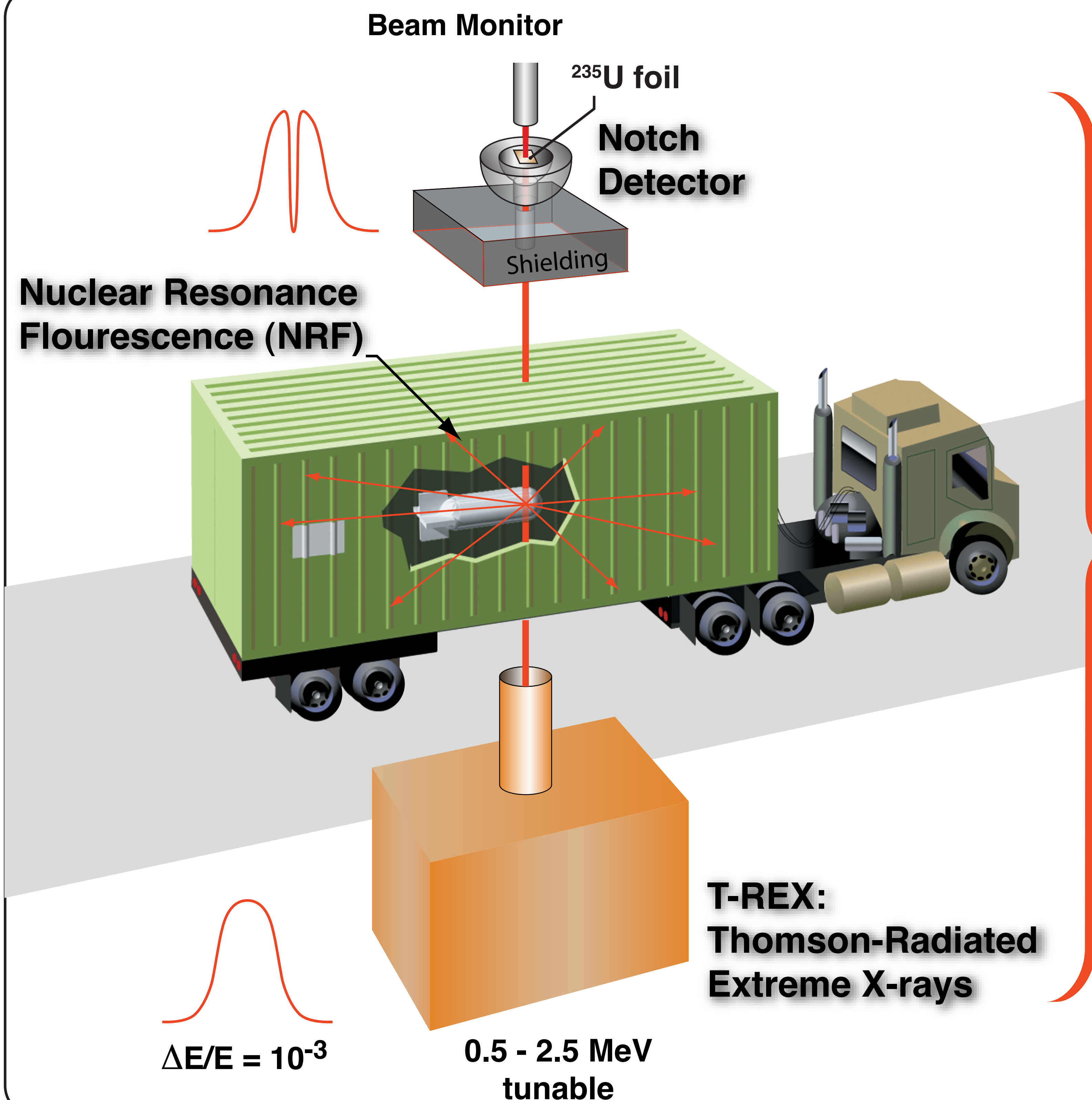
Fluorescent imaging with Thomson radiation is a new concept for isotopic detection of SNM



Fluorescent imaging with Thomson radiation is a new concept for isotopic detection of SNM



FINDER with Thomson-Radiated Extreme X-rays (T-REX) is a potential solution to the grand challenge of



FINDER: Fluorescence Imaging in the Nuclear Domain with Extreme Radiation

Unique FINDER Attributes

a) Quantifiably low false positive and false negative rates

b) An ability to “know when you don’t know”

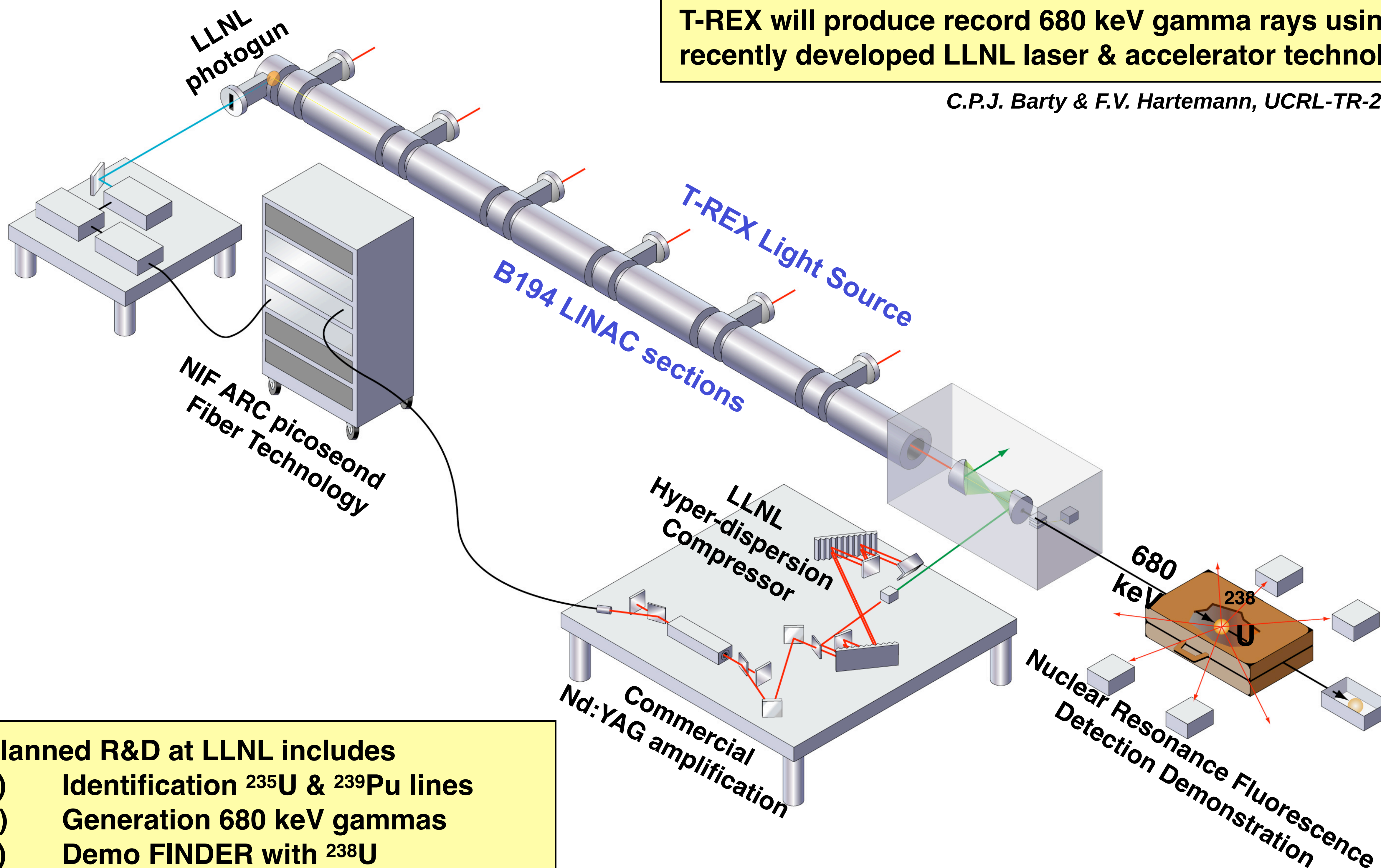
c) High spatial resolution “imaging”

d) Potential to detect non-radioactive materials and contraband

A ^{238}U demonstration of FINDER with a new 680 keV T-REX source is currently under development at LLNL

T-REX will produce record 680 keV gamma rays using recently developed LLNL laser & accelerator technology.

C.P.J. Barty & F.V. Hartemann, UCRL-TR-206825



Planned R&D at LLNL includes

a) Identification ^{235}U & ^{239}Pu lines
b) Generation 680 keV gammas
c) Demo FINDER with ^{238}U
d) FINDER & T-REX modeling

Center for Nuclear Photo-Science